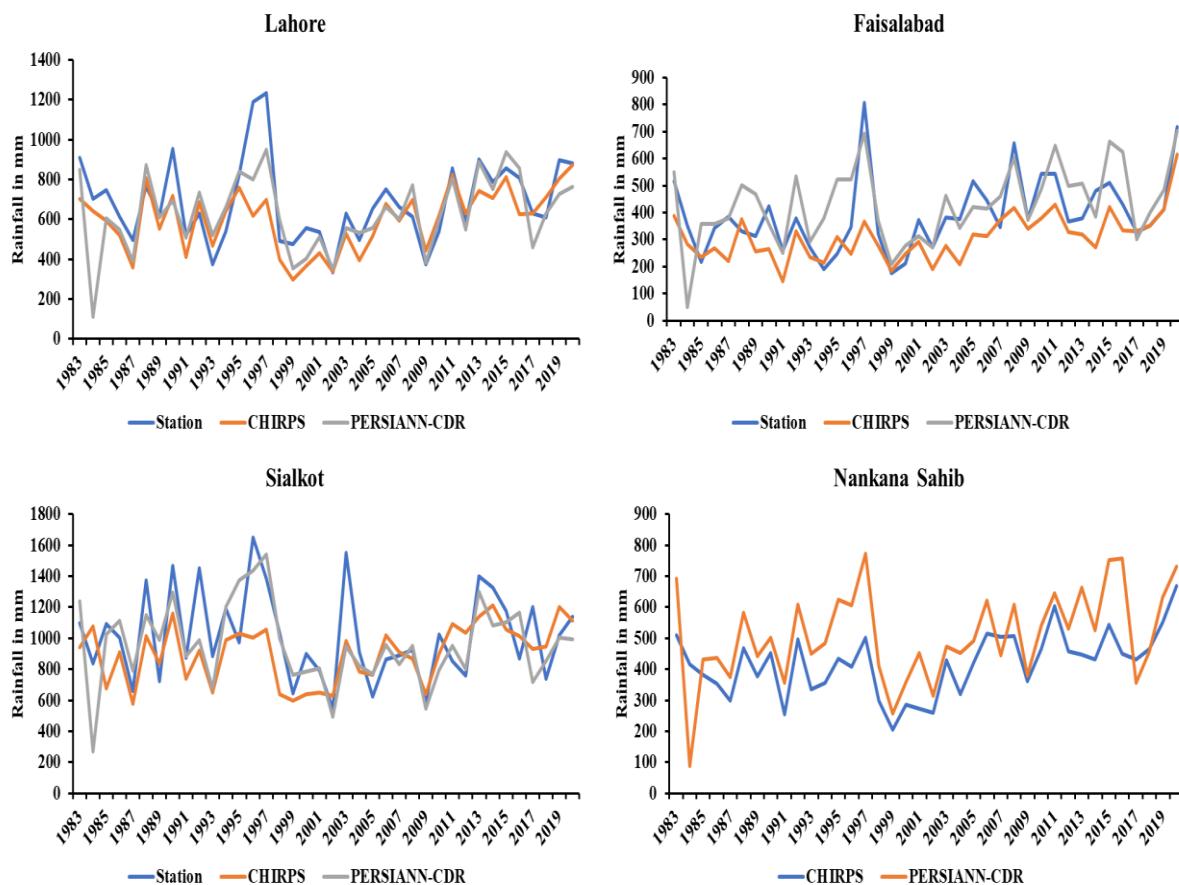


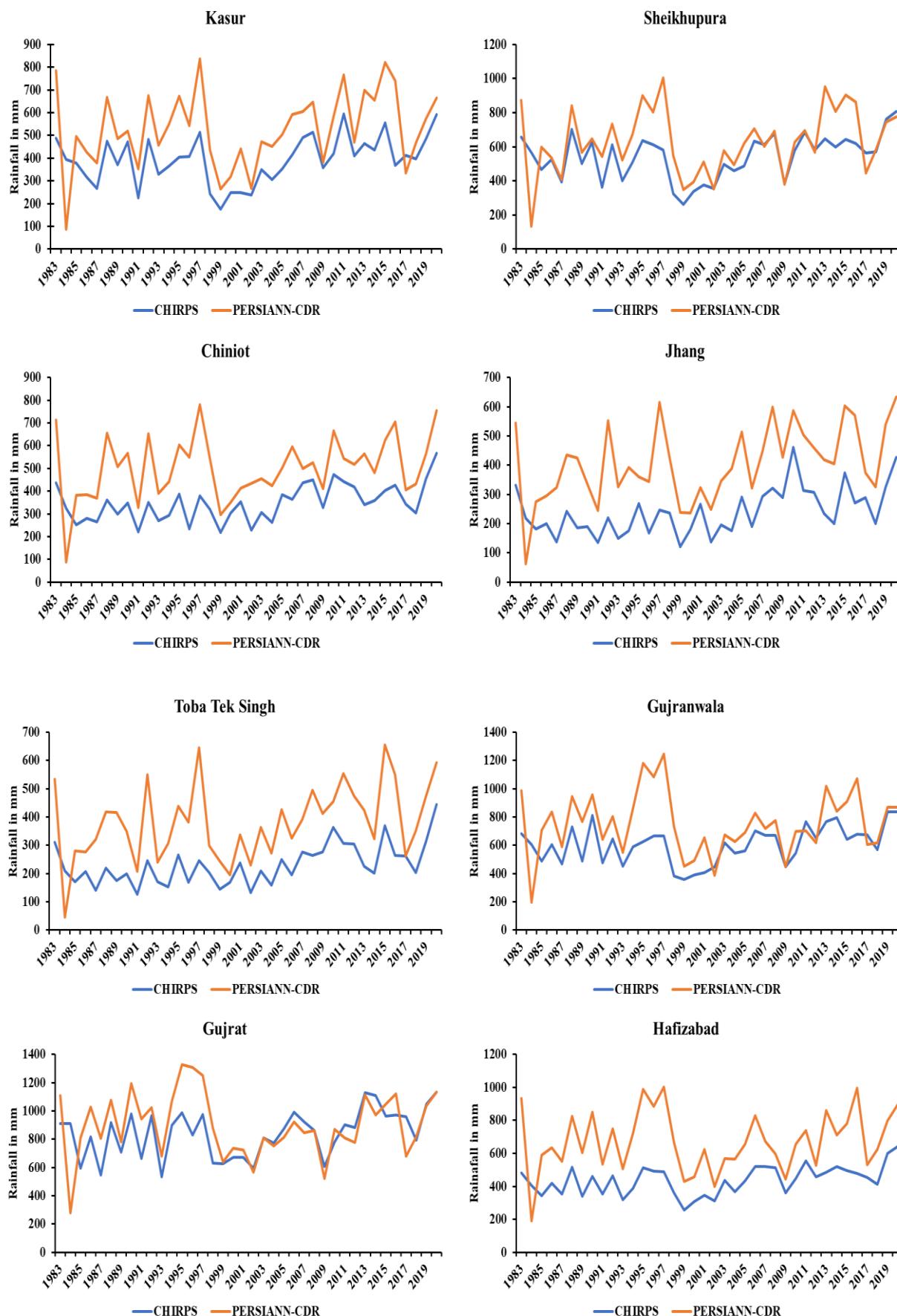


Supplementary Materials

Assessment of Long-Term Rainfall Variability and Trends Using Observed and Satellite Data in Central Punjab, Pakistan

Khalil Ahmad, Abhishek Banerjee, Wajid Rashid, Zilong Xia, Shahid Karim and Muhammad Asif





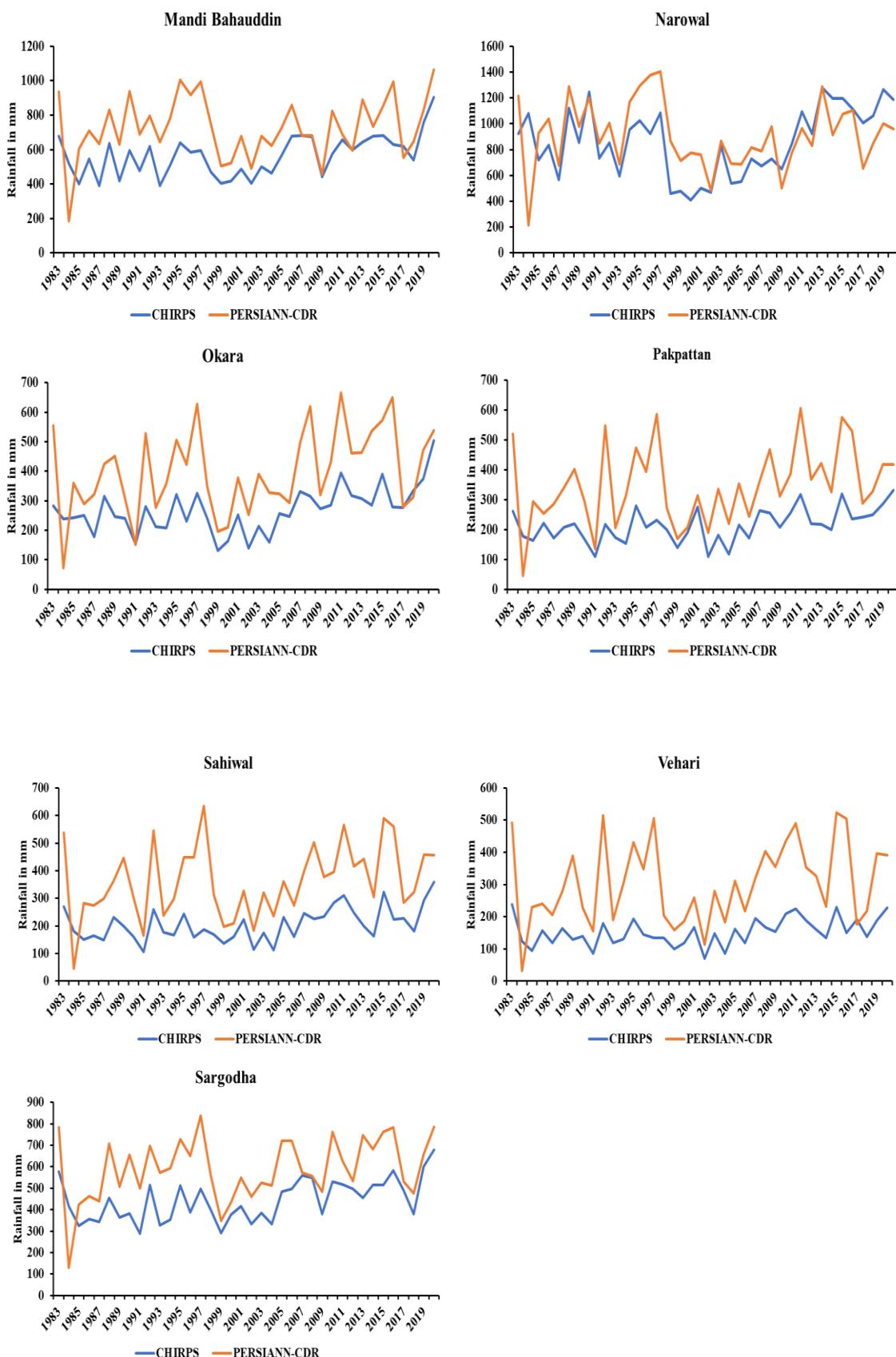
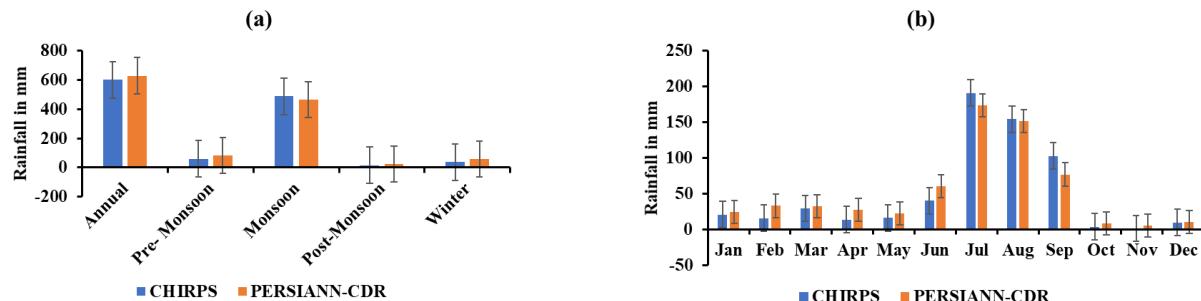
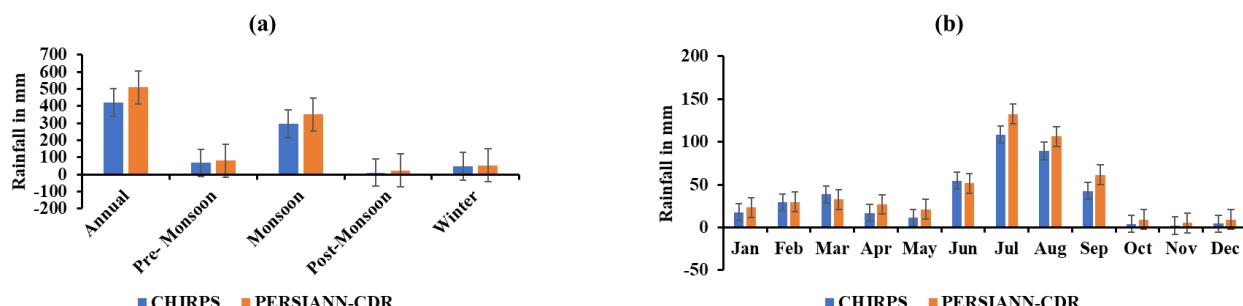


Figure S1. Annual distribution of rainfall of CHIRPS, PERSIANN-CDR and Observed datasets.

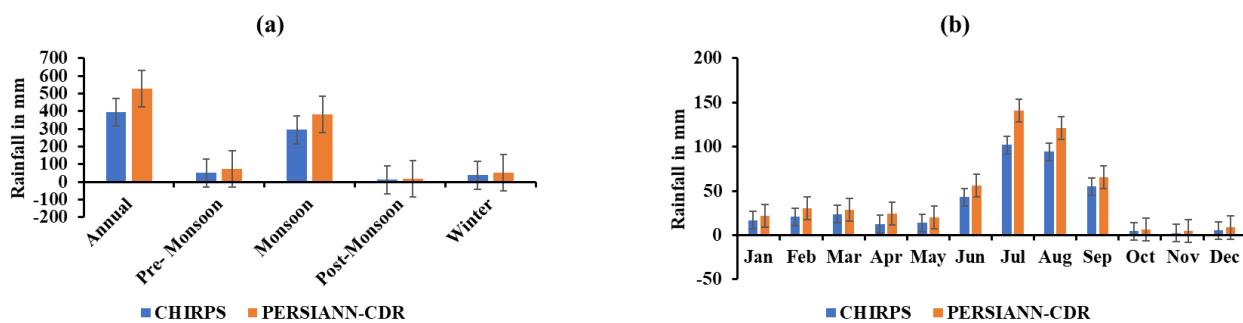
1. Lahore.



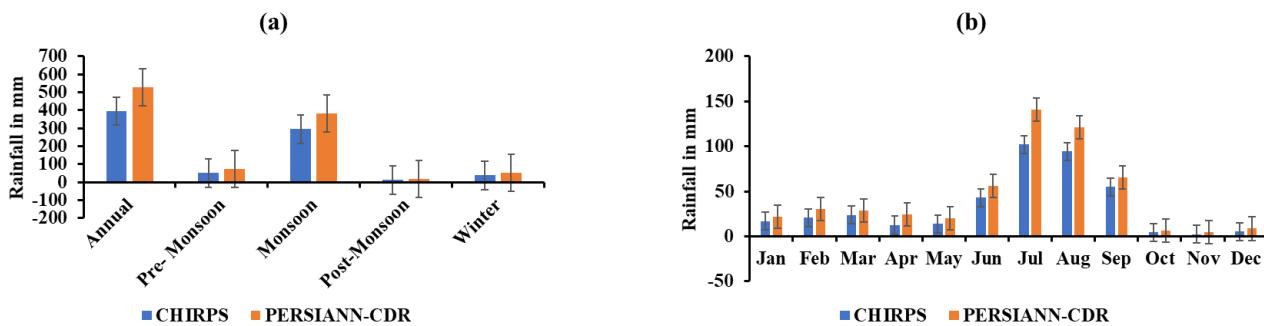
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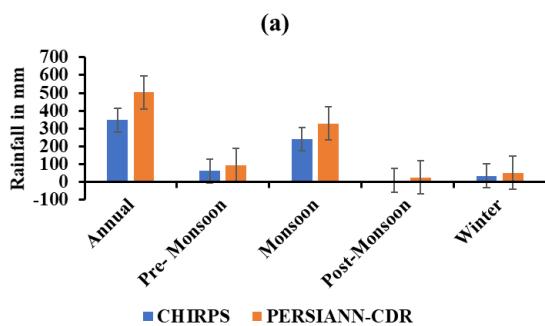
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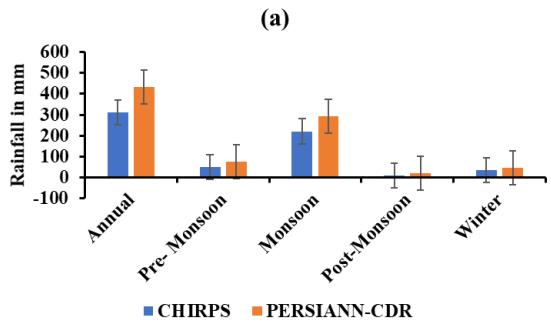
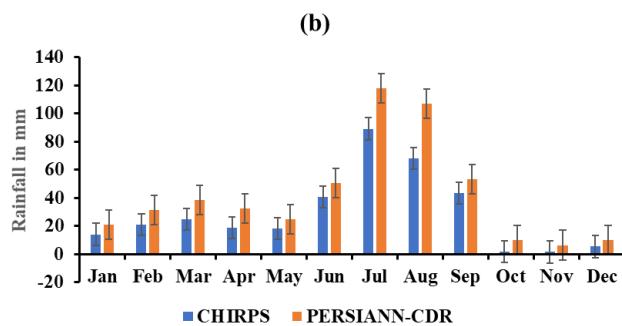
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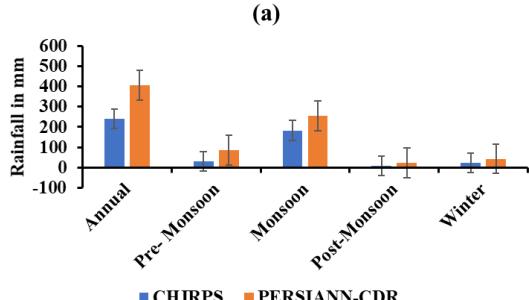
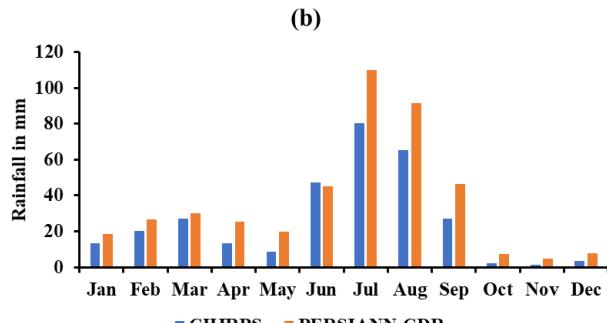
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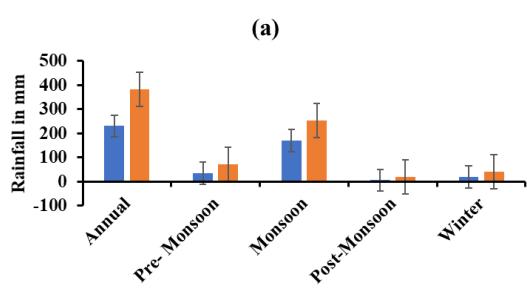
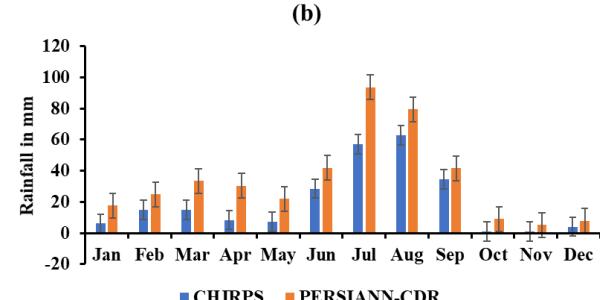
6. Faisalabad.



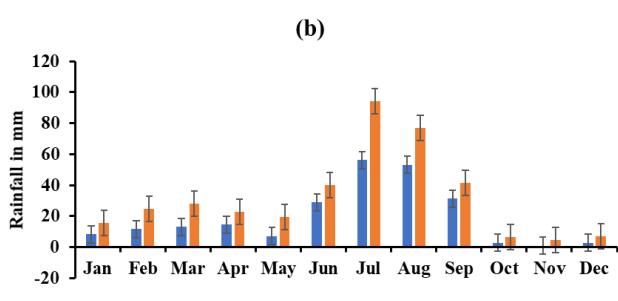
7. Jhang.

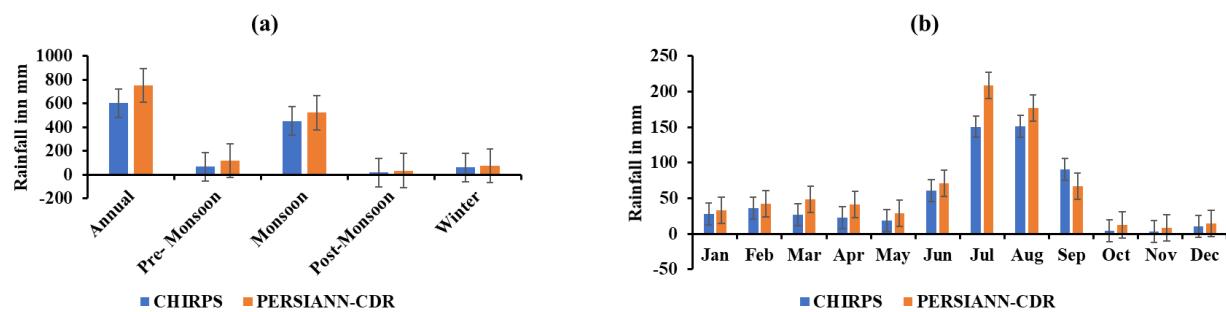


8. Toba Tek Singh.

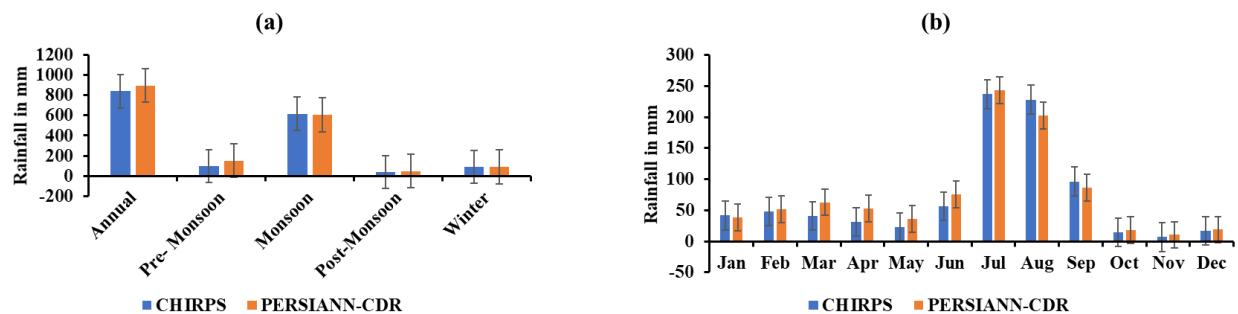


9. Gujranwala.

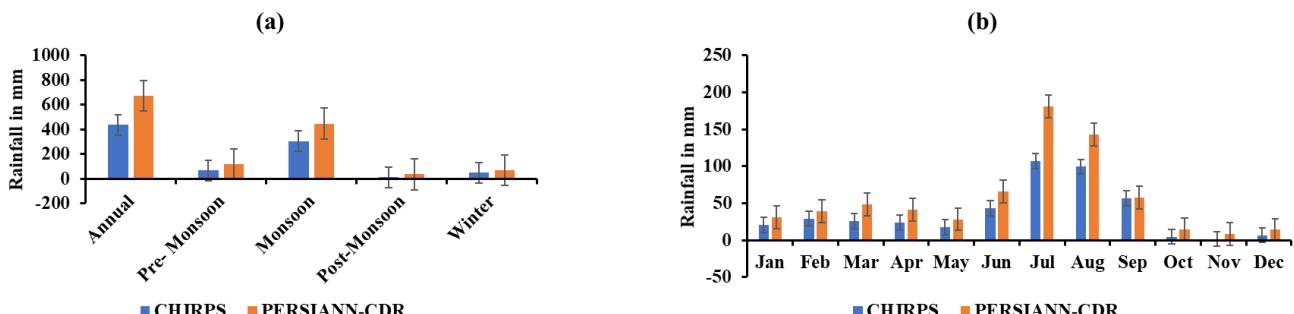




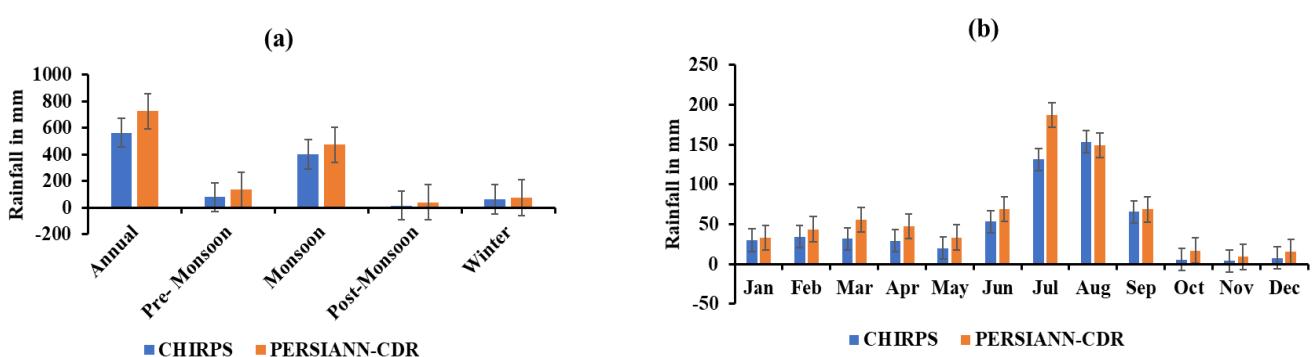
10. Gujarat.



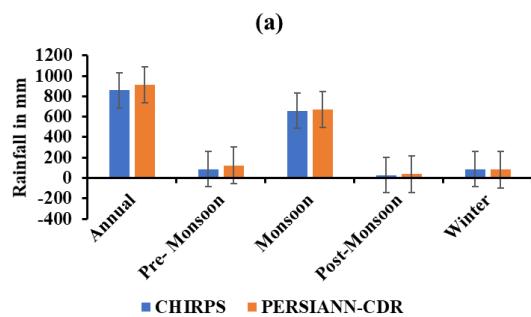
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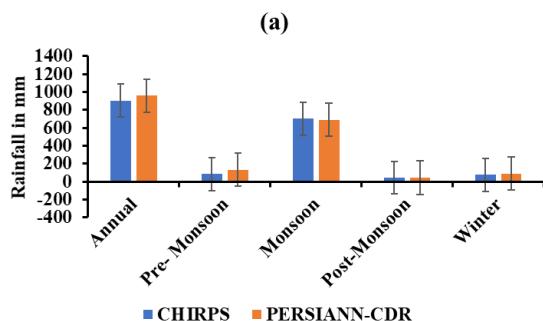
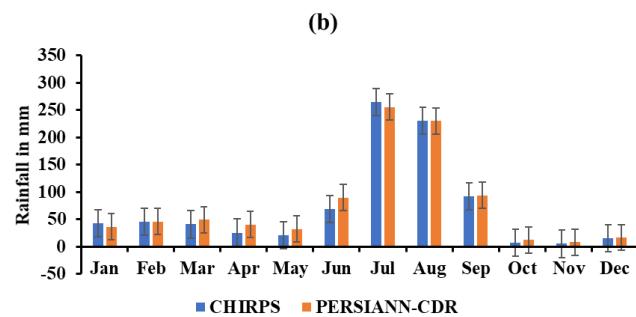
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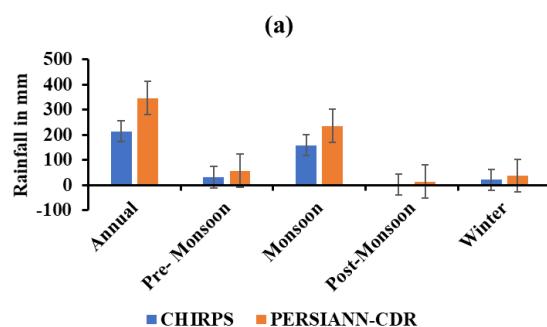
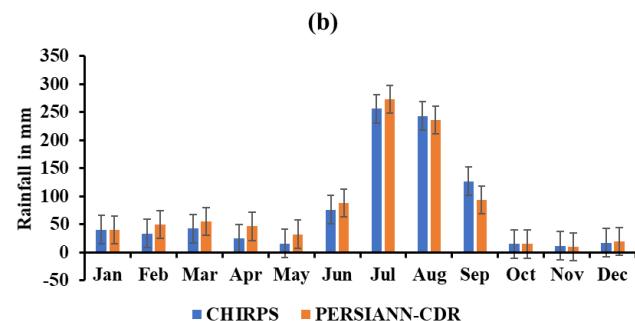
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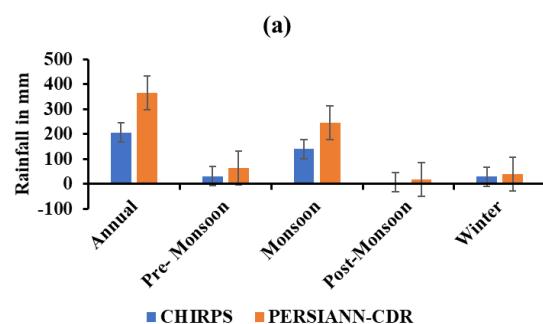
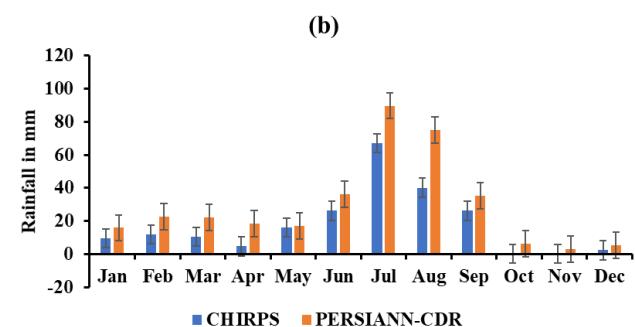
14. Sialkot.



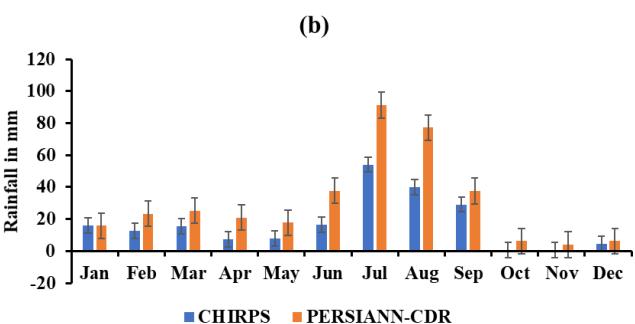
15. Pakpattan.

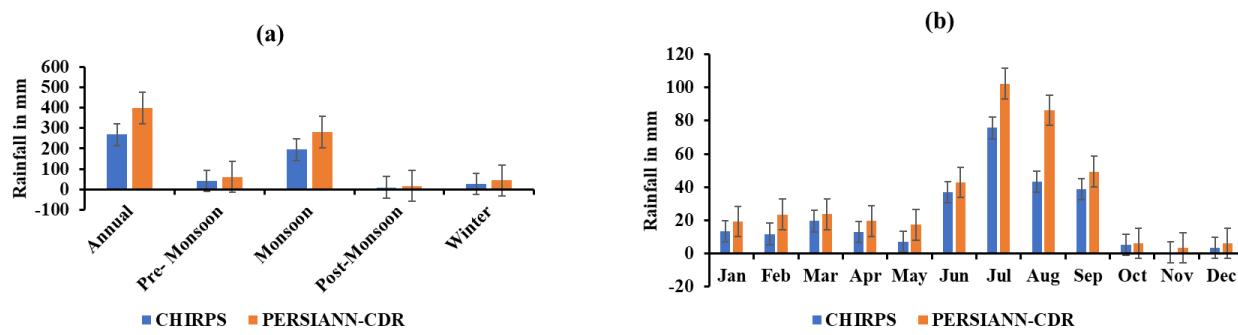


16. Sahiwal.

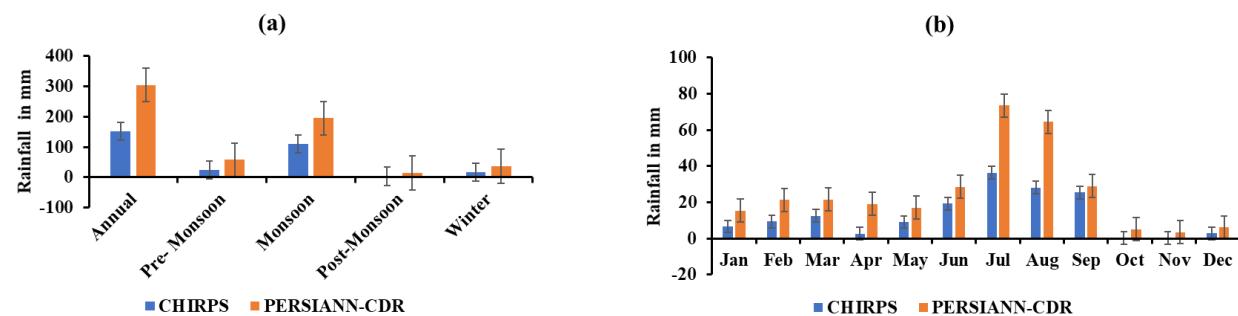


17. Okara.





18. Vehari.



19. Sargodha.

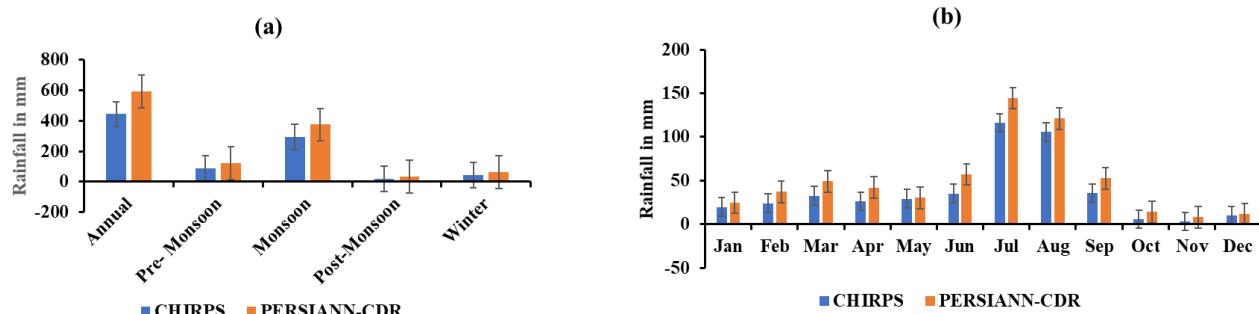


Figure S2. Seasonal distribution of rainfall of CHIRPS, PERSIANN-CDR and Observed datasets.

Table S1. Distributions of mean annual, seasonal, and monthly rainfall in central Punjab districts (1983–2020).

Station	Data	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Pre-Monsoon	Monsoon	Post-Monsoon	Winter
Vehari	CHIRPS	6.7	9.5	12.6	2.7	9.1	19.3	36.4	28.2	25.4	0.22	0.3	2.8	152.9	24.3	109.2	3.2	16.1
	PERSIA NN-CDR	15.4	21.3	21.6	19.2	17.1	28.6	73.6	64.4	28.9	5.0	3.5	6.1	304.8	57.9	195.6	14.7	36.7
Toba Tek Singh	CHIRPS	8.3	11.6	13.2	14.5	7.2	29.0	56.2	53.1	31.4	2.9	0.9	2.8	230.9	34.8	169.8	6.5	19.8
	PERSIA NN-CDR	15.6	24.6	28.1	22.9	19.5	40.1	94.4	76.9	41.5	6.5	4.6	6.9	381.9	70.5	252.9	18.2	40.3

Sialkot	CHIRPS	40.8	33.7	42.5	24.8	15.8	75.8	255.9	243.5	127.1	6	14.9	11.8	17.6	904.24	83.12	702.40	44.24	74.5
	PERSIA	40.5	49.6	54.9	46.4	32.6	88.6	272.7	235.5	93.7	14.9	9.7	19.3	958.5	133.9	690.5	43.9	90.1	
	NN-CDR																		
Sheikhu	CHIRPS	21.7	24.7	34.1	8	20.4	16.9	53.0	158.5	137.3	56.33	7.8	3.4	8.2	542.41	71.5	405.2	19.4	46.4
pura	PERSIA	27.2	34.1	36.9	31.9	24.4	60.7	171.7	144.4	72.6	9.22	6.52	11.5	631.1	93.3	449.3	27.2	61.3	
	NN-CDR																		
Sargodh	CHIRPS	19.8	23.9	32.6	26.5	29.1	35.2	116.4	105.5	35.8	5.9	3.3	10.1	444.1	88.2	292.9	19.3	43.8	
a	PERSIA	24.5	37.1	49.0	41.9	30.3	57.2	144.4	121.0	52.5	14.1	8.0	11.8	591.8	121.2	375.1	33.9	61.5	
	NN-CDR																		
Sahiwal	CHIRPS	15.9	12.7	15.7	7.5	7.7	16.5	54.1	40.1	29.2	0.7	0.7	4.4	205.3	30.9	139.9	5.9	28.6	
	PERSIA	15.8	23.4	25.2	21.0	17.7	37.8	91.2	77.3	37.6	6.2	4.1	6.2	363.7	63.9	243.9	16.6	39.2	
	NN-CDR																		
Pakpatta	CHIRPS	9.7	11.9	10.5	4.6	15.9	26.1	66.9	40.1	26.1	0.1	0.3	2.3	214.7	31.0	159.3	2.7	21.6	
n	PERSIA	15.9	22.7	22.2	18.5	16.9	36.2	89.7	74.9	35.2	6.2	3.0	5.3	346.9	57.7	236.1	14.6	38.6	
	NN-CDR																		
Okara	CHIRPS	13.3	11.8	19.6	12.9	7.1	36.9	75.7	43.2	38.8	5.4	0.6	3.4	268.5	39.7	194.5	9.4	25.1	
	PERSIA	19.3	23.6	23.6	19.5	17.3	42.9	102.3	86.3	49.3	6.2	3.4	6.2	400.0	60.4	280.9	15.9	42.9	
	NN-CDR																		
Narowal	CHIRPS	42.6	45.6	40.9	25.7	20.8	69.2	264.7	230.4	92.4	6.9	5.4	15.8	860.4	87.4	656.7	28.1	88.2	
	PERSIA	36.8	45.8	49.5	40.4	32.2	90.1	255.9	230.3	94.1	12.5	8.3	16.9	912.9	122.1	670.5	37.8	82.5	
	NN-CDR																		
Nankana	CHIRPS	17.9	29.3	38.8	16.8	11.3	54.7	108.4	89.4	42.7	4.2	2.04	4.5	419.9	66.8	295.1	10.7	47.2	
Sahib	PERSIA	23.2	29.6	32.7	26.9	21.3	51.6	132.4	106.1	61.3	8.9	5.3	9.2	508.7	80.9	351.4	23.5	52.9	
	NN-CDR																		
Mandi	CHIRPS	29.9	34.5	31.5	29.2	19.9	53.2	131.3	153.3	65.4	5.7	3.8	7.5	565.1	80.7	403.1	16.9	64.3	
Bahauddin	PERSIA	32.8	43.7	55.4	47.1	33.2	68.9	187.2	148.9	68.7	16.9	8.9	15.3	726.9	135.7	473.6	41.2	76.5	
	NN-CDR																		
Lahore	CHIRPS	20.8	15.8	29.6	13.9	16.5	40.5	191.1	154.5	102.9	4.0	1.6	9.7	600.54	59.70	488.89	15.34	36.61	
	PERSIA	24.9	33.1	32.3	27.6	22.9	60.9	174.2	151.9	77.1	8.2	5.7	10.8	629.6	82.82	463.9	24.8	58.0	
	NN-CDR																		
Kasur	CHIRPS	16.7	20.5	23.8	12.4	14.0	42.9	102.2	94.4	54.9	4.4	2.2	5.3	393.7	50.2	294.4	11.9	37.2	
	PERSIA	21.9	30.0	28.9	24.6	19.9	55.9	140.7	121.4	65.8	6.5	4.4	8.5	528.6	73.4	383.9	19.4	51.9	
	NN-CDR																		
Jhang	CHIRPS	6.1	14.9	14.9	8.4	7.3	28.6	56.9	62.9	34.7	1.1	0.9	4.1	241.1	30.6	183.2	6.2	21.0	
	PERSIA	17.7	24.9	33.5	30.5	22.0	41.9	93.7	79.5	41.6	9.1	5.1	7.9	407.2	85.9	256.6	22.0	42.6	
	NN-CDR																		
Hafizabadi	CHIRPS	21.0	29.4	25.9	23.9	17.7	43.6	107.2	99.4	56.8	4.7	1.7	6.8	437.9	67.5	306.9	13.5	50.4	
	PERSIA	31.1	39.5	48.5	41.2	28.4	65.8	181.2	143.2	58.1	14.4	8.5	14.1	673.9	118.1	448.2	36.9	70.6	
	NN-CDR																		
Gujrat	CHIRPS	41.6	47.9	41.0	31.9	22.9	56.3	236.9	228.3	96.5	14.4	6.9	16.7	840.9	95.6	618.0	37.9	89.5	
	PERSIA	38.7	51.5	62.9	52.9	36.2	75.8	243.7	202.8	86.6	18.1	10.7	19.1	898.7	151.9	608.7	47.8	90.2	
	NN-CDR																		
Gujranwala	CHIRPS	27.5	36.2	26.9	22.4	18.9	60.7	150.7	151.2	90.9	3.9	3.3	10.8	603.9	68.3	453.6	18.1	63.9	
	PERSIA	32.6	42.6	48.6	41.1	29.3	71.2	208.5	176.8	66.9	12.8	8.7	14.3	753.5	119.0	523.5	35.8	75.2	
	NN-CDR																		
Faisalabad	CHIRPS	13.3	20.	27.3	0	13.3	8.6	47.1	80.4	65.4	27.1	2.4	1.3	3.6	309.9	49.2	220.1	7.2	33.4

	PERSIA	18.3	26.8	30.0	25.2	19.7	45.0	109.9	91.6	46.3	7.5	4.7	7.7	432.9	74.9	292.9	19.9	45.1
	NN-CDR																	
	CHIRPS	14.1	20.9	24.8	18.8	18.3	40.6	89.2	68.1	43.6	1.9	1.6	5.5	347.3	61.9	241.5	8.9	35.0
Chiniot	PERSIA																	
	NN-CDR	20.9	31.4	38.7	32.3	24.8	50.6	117.9	106.9	53.2	10.2	6.5	9.9	503.5	95.7	328.8	26.6	52.3

Table S2. District-wise annual, seasonal, and monthly trends of rainfall of gridded datasets (mm/decade, 1983–2020).

Station	Data	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Pre-Monsoon	Monsoon	Post-Monsoon
Vehari	CHIRPS	0.28	0.37	0.03	1.26	2.4	1.8	1.9	0.7	0.9	0.0	0.0	0.0	9.6	3.6	5.3	0.0
	PERSIAN N-CDR	2.01	2.84	0.7	3.9	2.8	3.3	-4.1	1.4	3.4	0.0	0.9	-0.1	17.1	7.4	4.0	0.9
Toba Tek Singh	CHIRPS	0.5	0.4	0.6	3.8	1.9	5.1	6.9	0.2	3.5	0.0	0.0	0.0	23.1	6.3	15.8	0.0
	PERSIAN N-CDR	1.9	3.6	0.9	4.9	3.7	9.2	4.4	0.3	5.5	0.5	1.6	-0.3	36.1	9.4	19.4	1.7
Sialkot	CHIRPS	5.3	4.6	-3.2	3.7	0.3	11.7	10.3	-1.6	6.8	0.0	0.3	-0.8	37.3	0.8	27.2	-0.6
	PERSIAN N-CDR	1.4	2.1	-5.5	1.3	3.2	7.8	-29.1	-5.8	6.2	0.0	1.5	-1.6	-18.5	-0.9	-20.9	-0.1
Sheikhupura	CHIRPS	2.4	1.8	-0.6	2.3	2.6	8.2	7.9	-1.1	4.2	0.0	0.0	-0.3	27.2	4.2	19.2	-0.3
	PERSIAN N-CDR	2.6	3.7	-2.8	3.9	3.9	7.0	-6.6	1.7	14.5	0.7	1.2	-0.7	29.1	5.0	16.5	1.2
Sarghoda	CHIRPS	1.5	1.4	0.8	6.7	4.9	8.5	8.5	1.6	6.1	0.0	0.0	-0.5	39.5	12.4	24.7	-0.5
	PERSIAN N-CDR	2.3	5.3	-2.5	5.4	5.2	13.1	-2.2	-1.5	7.3	0.4	1.6	-0.6	34.1	8.2	16.8	1.5
Sahiwal	CHIRPS	0.7	0.4	0.6	2.1	1.7	1.9	7.0	0.1	2.1	0.0	0.0	-0.2	16.4	4.3	11.1	-0.2
	PERSIAN N-CDR	2.0	2.6	0.0	4.0	3.4	7.5	-0.7	1.6	7.2	0.0	1.2	0.0	28.5	7.4	15.3	1.2
Pakpattan	CHIRPS	0.3	0.4	0.2	1.5	2.9	3.6	5.0	-0.3	1.2	0.0	0.0	0.0	14.9	4.6	9.6	0.0
	PERSIAN N-CDR	1.9	2.5	0.4	3.4	2.8	2.5	0.5	3.2	7.7	0.0	0.8	0.1	25.8	6.6	13.9	0.9
Okara	CHIRPS	0.9	0.3	0.4	1.9	1.8	4.5	6.1	1.6	1.9	0.0	0.0	0.0	19.4	4.5	14.1	0.0
	PERSIAN N-CDR	1.9	2.8	1.1	3.8	3.3	2.2	-5.6	4.5	10.6	0.0	0.8	0.0	25.7	8.2	11.9	0.8
Narowal	CHIRPS	5.4	3.9	-2.5	2.9	0.3	12.1	12.1	8.5	5.1	0.4	0.0	-0.3	47.9	0.8	37.7	0.1
	PERSIAN N-CDR	0.9	2.0	-5.1	2.19	2.8	8.9	-29.1	2.5	10.6	0.0	1.6	-1.1	-4.2	-0.5	-7.2	0.5
Nankana Sahib	CHIRPS	1.8	0.3	-1.8	2.9	2.3	7.5	7.3	2.2	2.7	0.0	0.0	0.0	25.4	3.5	19.8	0.0
	PERSIAN N-CDR	2.7	3.3	-0.3	3.3	4.5	7.6	-0.8	2.8	12.5	0.9	1.2	-0.2	37.3	7.5	22.1	1.9
Mandi	CHIRPS	3.1	2.3	-0.2	7.2	3.7	9.4	6.8	1.6	7.7	0.0	0.0	0.0	41.7	10.7	25.5	0.0
Bahauddin	PERSIAN N-CDR	2.6	5.5	-6.0	4.6	4.2	8.6	-6.0	-11.2	14.0	1.4	1.7	-1.1	18.2	2.7	5.4	2.0
Lahore	CHIRPS	2.1	1.6	-0.4	1.8	2.2	7.3	7.0	0.5	4.4	0.0	0.0	-0.2	26.3	3.6	19.2	-0.2
	PERSIAN N-CDR	3.2	2.3	-0.8	2.5	3.9	7.7	-11.8	10.1	12.3	0.0	1.1	-0.5	30.3	5.7	18.4	0.6
Kasur	CHIRPS	1.2	0.9	-0.4	1.6	1.8	5.0	1.9	0.5	1.6	0.0	0.0	-0.5	13.8	3.03	9.1	-0.5

	PERSIAN N-CDR	2.9	2.4	-0.2	4.4	3.6	7.0	-8.5	5.2	13.1	0.3	1.1	-0.4	30.8	7.8	16.8	0.9
Jhang	CHIRPS	0.5	0.5	1.9	2.7	1.2	7.9	6.3	2.1	5.7	0.0	0.0	0.0	28.6	5.7	21.9	0.0
	PERSIAN N-CDR	2.6	3.9	0.9	5.5	3.2	9.1	8.4	-0.3	6.3	0.0	1.8	-0.3	41.0	9.7	23.5	1.4
Hafizabab d	CHIRPS	1.7	1.9	0.1	4.4	2.7	8.1	3.5	-2.5	3.1	0.0	0.0	-0.2	22.9	7.2	12.2	-0.1
	PERSIAN N-CDR	3.7	4.9	-3.6	4.9	4.8	7.5	-12.1	-3.4	9.9	0.6	1.3	-0.7	17.2	6.2	1.2	1.2
Gujrat	CHIRPS	5.4	6.4	-0.1	5.54	2.9	8.8	7.3	3.6	9.6	2.2	0.4	-1.5	50.8	8.5	29.4	1.1
	PERSIAN N-CDR	2.2	4.8	-9.9	2.1	3.9	11.7	-20.1	-11.7	14.9	0.3	1.2	-1.9	-2.3	-3.9	-5.2	-0.3
Gujranw ala	CHIRPS	3.5	4.5	-0.0	3.3	1.9	9.6	2.5	2.9	5.8	0.0	0.0	-1.2	32.8	5.1	20.7	-1.5
	PERSIAN N-CDR	3.3	4.8	-4.8	2.5	3.4	5.9	-11.5	2.5	8.1	0.5	1.2	-1.25	14.6	1.0	5.1	0.4
Faisalaba d	CHIRPS	0.4	0.9	0.8	2.6	1.9	8.9	11.2	1.9	3.4	0.0	0.0	0.0	31.9	5.3	25.5	0.0
	PERSIAN N-CDR	2.5	2.6	1.2	4.9	4.0	5.9	-0.6	1.6	10.0	0.6	1.7	-0.1	34.4	10.5	17.01	2.5
Chiniot	CHIRPS	0.9	1.2	1.1	4.6	2.8	8.9	4.0	1.7	5.8	0.0	0.0	0.0	30.9	8.4	20.5	0.0
	PERSIAN N-CDR	3.0	3.8	-0.5	5.7	5.0	7.6	-0.7	-2.1	6.7	0.0	1.2	-0.3	29.6	10.2	11.6	0.9

Bold characters are statistically significant at 95% significance level.

Table S3. Phase-wise annual, seasonal, and monthly trends of rainfall in central Punjab (CHIRPS, PERSIANN-CDR).

Data	Perio d	Jan	Feb	Mar	Apr	Ma y	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annu al	Pre- Monso on	Monsoo n	Post- Monsoo n	Winter
CHIRPS	1983- 2001	0.1	-0.5	-0.9	-0.0	0.0	0.3	-0.4	-2.5	-0.7	-0.1	-0.0	-0.4	-4.9	-0.8	-3.2	-0.5	-0.4
	2002- 2020	0.6	0.2	1.0	0.9	0.5	0.5	3.3	2.1	0.7	0.1	0.1	-0.0	10.0	2.5	6.6	0.2	0.8
PERSIAN N-CDR	1983- 2001	0.9	-0.5	-1.7	-0.4	0.9	2.6	-1.6	-2.3	0.9	0.1	0.0	-0.7	-1.9	-1.2	-0.5	-0.5	0.3
	2002- 2020	1.1	0.1	1.2	1.8	0.6	0.3	1.9	0.9	-0.3	0.0	0.4	-0.1	7.9	3.6	2.9	0.3	1.2

Bold characters are statistically significant at 95% significance level.